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BIOLOGICAL AND CLIMATIC EFFECTS RESEARCH
TERRESTRIAL NON-HUMAN ORGANISMS

EXECUTIVE SUMMARY

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Project Officer:

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BACER Program
Washington, D.C. 20460

EXECUTIVE SUMMARY

This final report describes the research undertaken by the U.S. Department of Agriculture during the period of October 1, 1976, to February 28, 1978, as a part of the Biological and Climatic Effects Research (BACER) Program conducted under interagency agreement with the Environmental Protection Agency. The objective of this research was to assess the biological impact of increased radiation in the UV-B region (280-320 nm) reaching the earth's surface on agriculturally important and native terrestrial plants and animals that might result from stratospheric ozone reduction caused by inadvertent release of chlorofluoromethanes (CFM's).

The organizations reporting and participating in this research are listed below:

- U.S. Department of Agriculture
  - U.S. Forest Service, Fort Collins, Colorado
  - Science and Education Administration
    - Arizona-New Mexico Area, Las Cruces, New Mexico
    - Beltsville Agricultural Research Center, Beltsville, Maryland
      - Agricultural Equipment Laboratory
      - Chemical and Biophysical Control Laboratory
      - Florist and Nursery Crops Laboratory
      - Instrumentation Research Laboratory
      - Organic Chemical Synthesis Laboratory
      - Plant Stress Laboratory
    - Florida-Antilles Area, Gainesville, Florida
    - National Animal Disease Center, Ames, Iowa
    - Northern Regional Research Center, Peoria, Illinois

Federal Research Contracts

University of Florida, Fruit Crops Department, Gainesville, Florida

Colorado State University, Department of Horticulture, Fort Collins, Colorado

Major accomplishments resulting from the U.S. Department of Agriculture BACER Program are as follows:

1. An automatic UV spectroradiometer was designed, constructed and successfully tested capable of measuring UV radiation every nanometer (nm) from 250 to 400 nm, with a wavelength precision of 0.1 nm (1Å). Broad- and narrow-band radiometers to monitor the output of artificial UV sources for laboratory, growth chamber, and greenhouse experiments were also developed.

2. Substantially all major crops, including many horticultural species and varieties, and some native species have been screened for sensitivity to increased levels of UV-B.

3. Injury threshold levels were found to vary widely among species and within cultivars and varieties of the same species.

4. It was almost universally observed that field grown plants were more tolerant to enhanced UV-B levels than were the identical selections grown in greenhouses or controlled environment chambers. A seasonal difference in sensitivity to enhanced levels of UV-B was also observed, with plants showing greater tolerance during the summer months. Substantial evidence for the existence of a high-light intensity photorepair or photoprotection mechanism in higher plants was obtained.

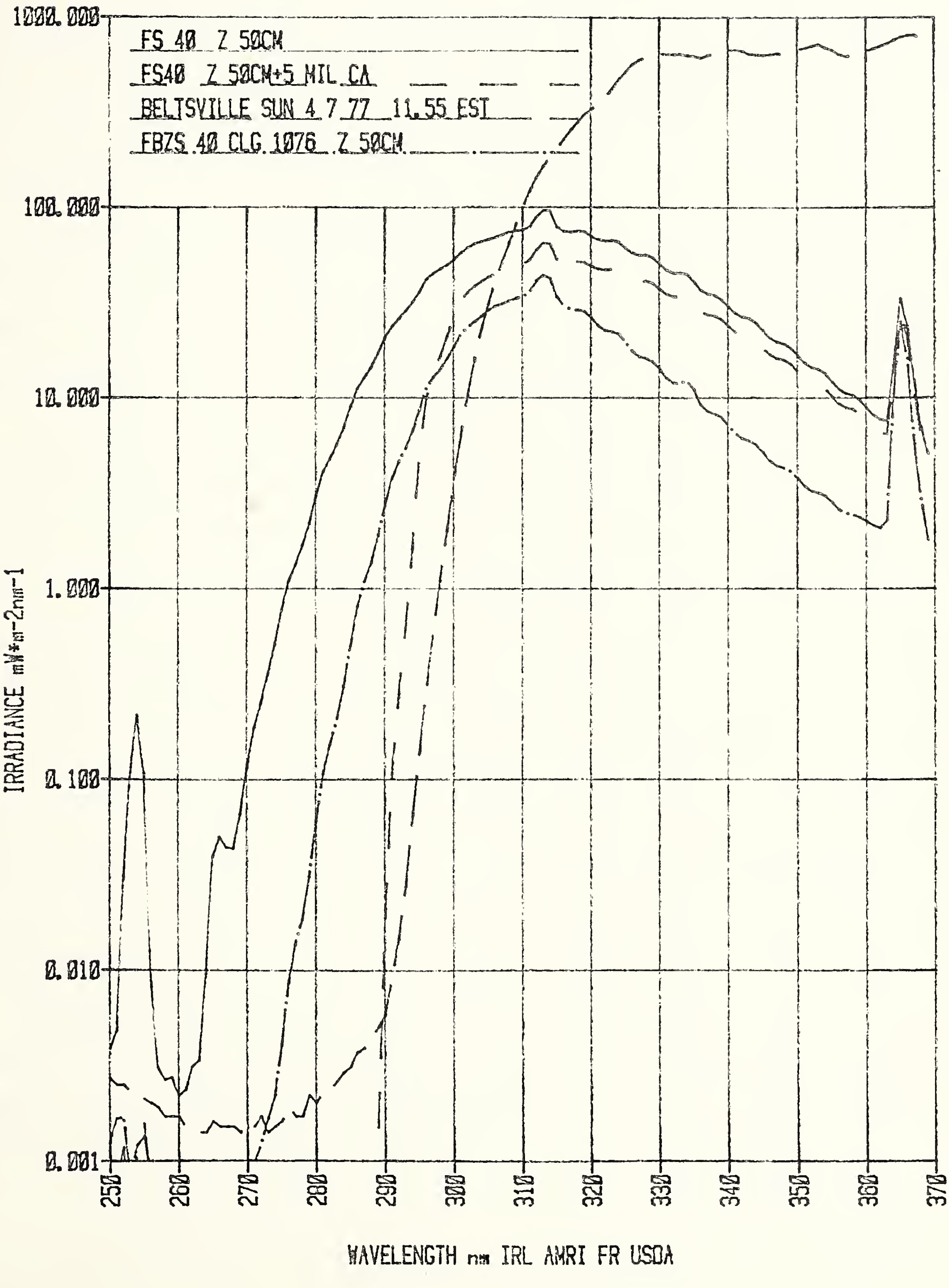
5. Some economic plant species, such as cantaloupe, soybeans, and cotton have been shown to be sensitive to present levels of UV-B reaching the earth's surface.
6. Highly pigmented insects, especially those with a high melanin content, were found to be highly resistant to UV-B. Honeybees, for example, were unaffected by very high levels of UV-B. Some leaf disease organisms display similar responses.
7. We have established that "cancer eye" may have been induced in Hereford cattle by high levels of UV-B.

These accomplishments provide a significant increase in knowledge of the potential responses of terrestrial plants and animals to increased UV-B irradiance. Because of continued uncertainties involved in this research, the results do not permit the development of conclusive statements concerning the possible harmful effects to be expected from increased UV-B reaching the earth's surface as a result of the projected reduction in stratospheric ozone as a result of release of the chlorofluoromethanes in the biosphere.

The uncertainties are addressed below:

Artificial Enhancement Sources. Because of technological problems, the short time frame for the projected research, and funding limitations, UV enhancement sources were almost entirely limited to UV-emitting fluorescent sun lamps from various sources. The spectral characteristics of these lamps do not simulate the sun's spectral characteristics. Figure 1 illustrates the discrepancies encountered. A comparison is shown between a spectroradiometer measurement of the sun taken at Beltsville, Maryland, May 13, 1977, at 1300 hours, and the various lamp and filter combinations used in these studies.

Figure 1


FS 40 Z 50CM
FS40 Z 50CM+5 MIL CA
BELTSVILLE SUN 4 7 77 11.55 EST
FBZS 40 CLG 1076 Z 50CM
1000.000
100.000
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IRRADIANCE mW*m-2nm-1
250
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330
340
350
360
370
WAVELENGTH nm IRL AMRI FR USDA

The first problem seen is that the region of major interest 280-320 nm is one of rapidly decreasing irradiance; decreasing over four orders of magnitude. Unfiltered lamps do not parallel this decrease in intensity, displaying higher intensities as the wavelength decreases. As can be seen, this discrepancy can be partially overcome by use of suitable filters; 5 mil cellulose acetate for example (+ 6 hrs. 5 m CA).

The second, and perhaps as serious a difference is the greatly decreased irradiance from artificial sources from approximately 310 nm and above. The possible effect of this reduced irradiance level in the UV-A region can only be conjectured at our present state of knowledge.

A third uncertainty, which we believe to be at least partially resolved is the fact that energy emitted by a fluorescent lamp and falling on a horizontal surface parallel to the long axis of the lamp is unequal; being highest directly under the center of the lamp and falling off rapidly in all directions from the center. By using improved instrumentation and through development of equations defining this energy variable, careful energy-defined biological research has been accomplished.

However, continued use of these sources for UV enhancement experiments will require improvements in UV filters and in the sensitivity, accuracy and utility of UV radiometer and spectroradiometer equipment. Development of new sources more nearly simulating the sun will prove expensive and probably require the development of new or improved technology.

Action Spectra. Since the artificial enhancement sources do not simulate the sun and because biological organisms and systems do not respond equally to all wavelengths of UV radiance, the interpretation of data derived from UV enhancement experiments requires the use of a suitable weighting

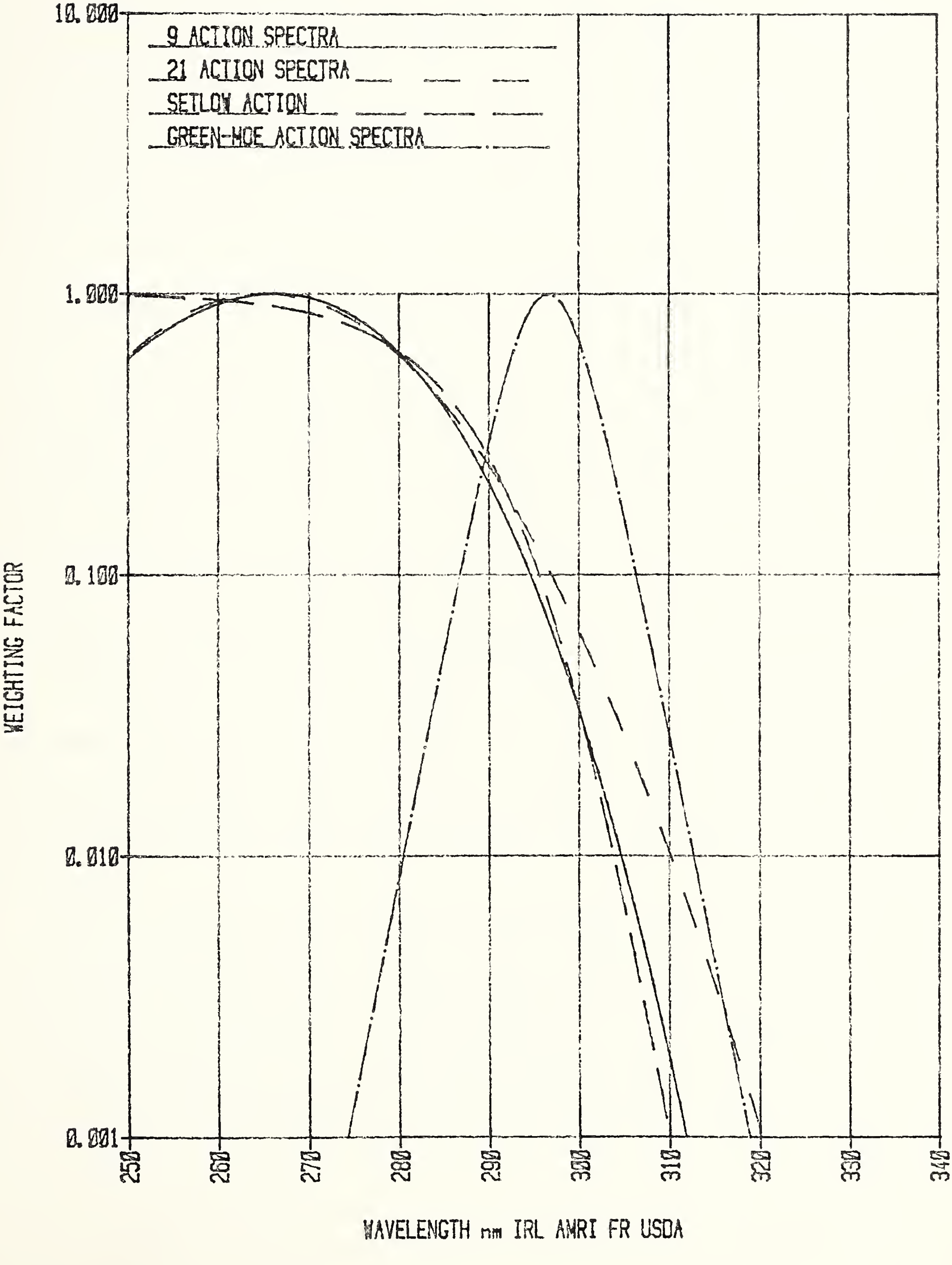
function derived from an action spectrum to describe the comparative biological effectiveness of different wavelengths in the UV region to which the organism is subjected. At the beginning of the short-term BACER program there was no universally accepted action spectrum for higher plants although several had been proposed (Figure 2). The two action spectra (AS) which have been evaluated for data interpretation in the current program are graphically shown as 9AS (AΣ9) and 21AS (AΣ21).

Weighting functions derived from these two spectra have been used by participating principal investigators. The 9AS weighting function has generally been applied by most researchers. However, the University of Florida and the Florida-Antilles Area report their results using the 21AS weighting function.

The Agricultural Equipment Laboratory report contains a presentation of results obtained by Beltsville Agricultural Research Center investigators which suggest that the 9AS weighting function is more valid than the 21AS weighting function. It should be emphasized, however, that data are still lacking as to how accurate or how universally applicable this weighting function will prove to be. Use of the 21AS weighting function in place of the 9AS tends to overestimate the effectiveness of the longer wavelengths thereby underestimating the amount of biologically effective UV radiation (BUV) received. Thus, test organisms are subjected to higher total UV irradiances with the 21AS weighting function than with the 9AS weighting function for a supposed equal amount of biologically effective UV.

To provide a basis for interlaboratory comparison of data, all principal investigators have provided irradiances used in experimental set-ups in absolute unweighted mWm^{-2} thus, when a verified action spectrum has been established, all submitted data may be reinterpreted on the basis of the accepted action spectrum.

Figure 2



10.000
1.000
0.100
0.010
0.001
9 ACTION SPECTRA
21 ACTION SPECTRA
SETLOW ACTION
GREEN-MOE ACTION SPECTRA
WEIGHTING FACTOR
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270
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290
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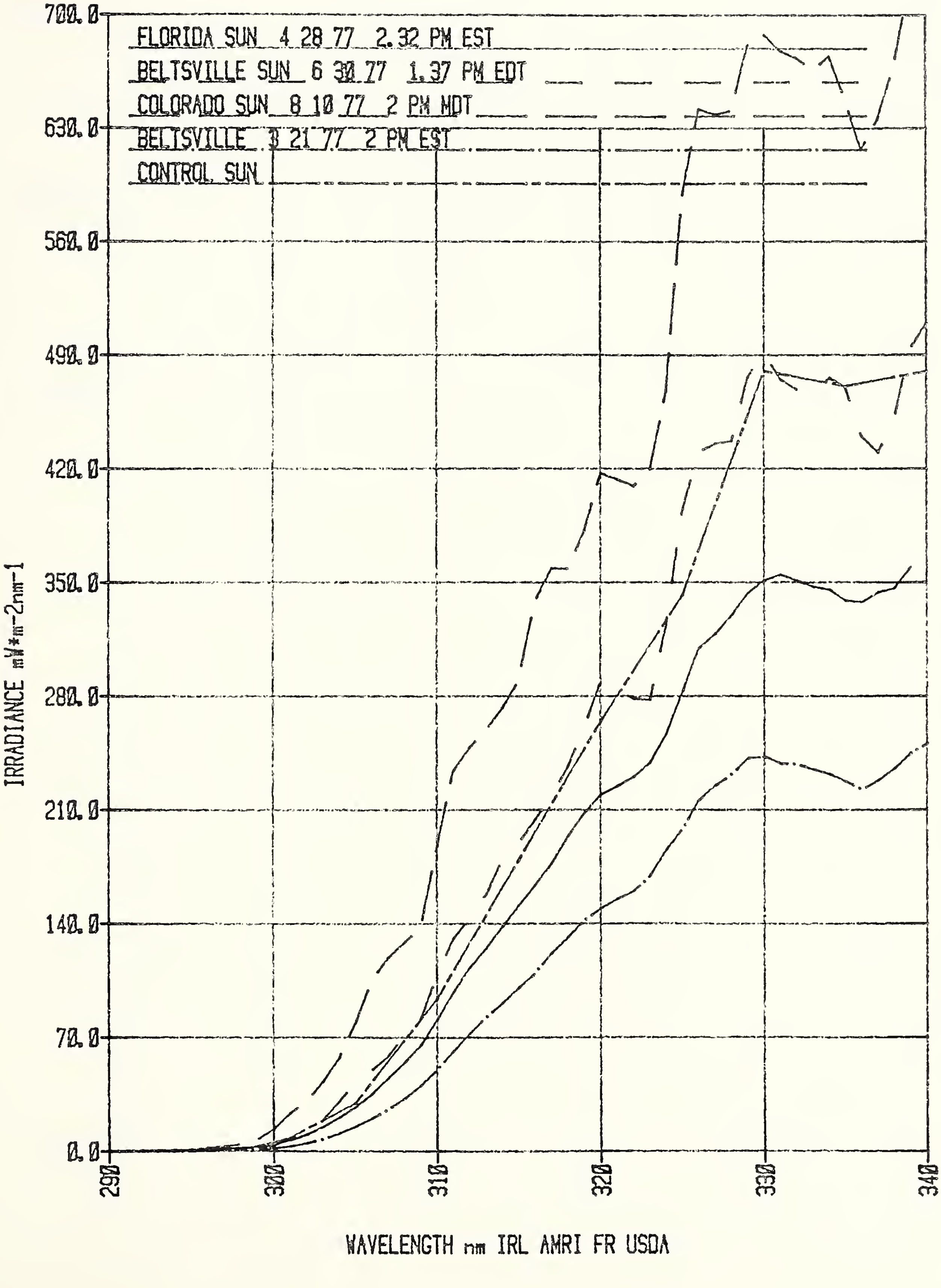
310
320
330
340
WAVELENGTH nm IRL AMRI FR USDA

Control Sunshine. Another major problem in interpretation of UV-irradiance enhancement studies is the variation in the sun's UV-irradiance as a function of latitude, elevation, zenith angle, and the sun's variability from day to day as the result of stratospheric and atmospheric changes. This is illustrated in Figures 3 and 4 showing linear and log plots of UV irradiances obtained every nanometer from 290-320 nm using a single or double monochromator spectroradiometer. Starting with the sun spectrum with the highest overall spectral energy, the data were obtained at: Snowmass, Colorado, 9,777 ft. (2980 m) on August 10, 1977, 1400 hours; Beltsville, Maryland, 186 ft. (56.7 m), June 30, 1977, 1337 hours; Gainesville, Florida, 180 ft. (54.9 m), April 28, 1977, 1432 hours, (University of Florida report, Table 10); and Beltsville, Maryland, March 21, 1977, 1400 hours. Asterisks on Figure 3 represent the control sunshine used by investigators at BARC derived from data obtained by the Smithsonian Radiation Research Laboratory, Rockville, Maryland, and the Instrumentation Research Laboratory, Beltsville, Maryland. It basically represents the average sunshine for the months of June and July 1976 in the Washington, D.C., area.

As can be seen on Figure 4, because of stray light response of the instrument used at Gainesville, Florida, irradiances are overestimated at the shorter wavelengths (290-300 nm); this presents a serious problem when weighting functions are required since greater weight is applied to shorter wavelengths.

Table 1 presents the total unweighted mWm^{-2} from 290-320 nm, the AΣ9 weighted mWm^{-2} and the fraction of one average control sunshine used in the Beltsville investigations. The biologically effective UV-B measured at Snowmass, Colorado, was 2.7 times that of the Washington, D.C., area. A 20 to 40 percent enhancement of the measured biologically effective UV-B

Figure 3


FLORIDA SUN 4 28 77 2.32 PM EST
BELTSVILLE SUN 6 30 77 1.37 PM EDT
COLORADO SUN 8 10 77 2 PM MDT
BELTSVILLE 3 21 77 2 PM EST
CONTROL SUN
700.0
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IRRADIANCE mW*m-2nm-1
290
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330
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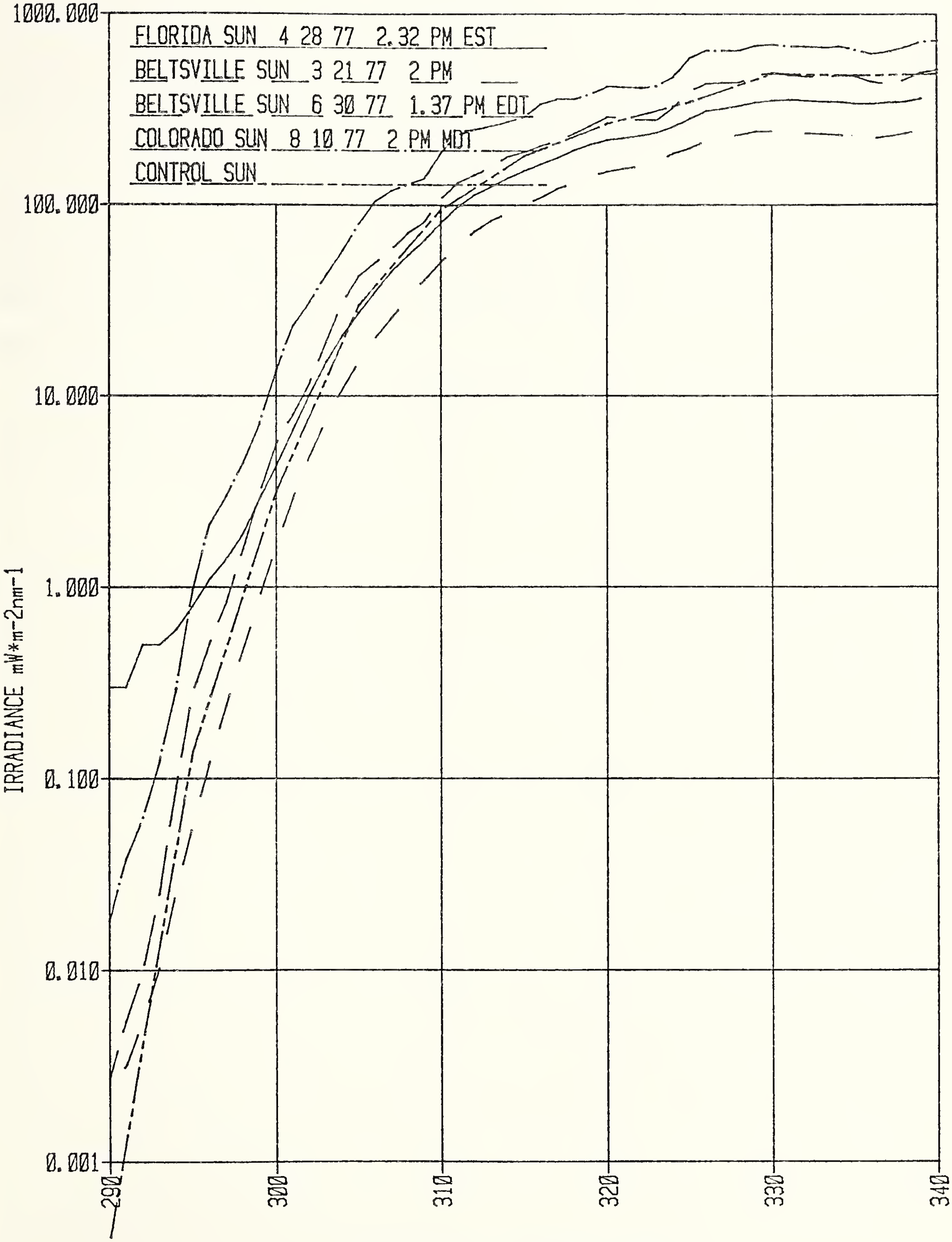
WAVELENGTH nm IRL AMRI FR USDA

Figure 4


FLORIDA SUN 4 28 77 2.32 PM EST
BELTSVILLE SUN 3 21 77 2 PM
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COLORADO SUN 8 10 77 2 PM MDT
CONTROL SUN
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IRRADIANCE mW*m-2nm-1
290
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WAVELENGTH nm IRL AMRI FR USDA

at the Colorado location would range from 9.95 to 11.61 weighted mWm^{-2}, whereas an identical enhancement at Washington, D.C., would range from 3.67 to 4.28 weighted mWm^{-2}. The need for biological research to cover a wide range of biologically effective UV-B irradiances is obvious.

To properly evaluate the results presented here United States-wide will require accurate knowledge of the sun's spectral energy in all geographic regions. The development of a program for regular monitoring of the UV spectral irradiance at selected locations is a necessity which cannot be ignored in future programs.

Research results obtained by each principal investigator are summarized in the following pages.

Table 1

Location	Total irradiance	Biologically effective UV irradiance AΣ9	Fraction of control sunshine
	290-320 nm mWm^{-2}	290-320 nm weighted mWm^{-2}	
Snowmass, CO	4098	8.29	2.7
Beltsville, MD (high)	2499	3.94	1.3
Gainesville, FL	1742	2.68	0.7
Beltsville, MD (low)	1274	1.60	0.5
Control sunshine (Beltsville)	2847	3.06	1.0

RESEARCH PROGRESS

Development of Instrumentation for Measuring UV-B Radiation

One of the most significant accomplishments made during the past year in support of the interagency BACER program was the development of improved instrumentation for monitoring and measuring UV-B radiation.

The Instrumentation Research Laboratory at Beltsville, Maryland, designed, constructed, and successfully tested an automatic UV spectroradiometer capable of measuring UV radiation every nanometer (nm) from 250 to 400 nm with a wavelength precision of 0.1 nm (or Å). This wavelength precision is necessary to detect small changes in UV radiation since a 1-nm change in UV radiation is equivalent to approximately a 16 percent change in ozone concentration.

Significant design features of this instrument include: a single or double monochromator with holographic gratings; a variable-speed-motor drive to scan the entire UV region in less than 5 minutes; a specially designed teflon bubble diffuser for cosine correction of the incoming UV radiation; a solar blind filter or a solar blind phototube; and an amplifier output digitized with a digital voltmeter which is interfaced with a desk-top programmable calculator.

As the spectrum is scanned, the programmable calculator corrects the measured signal for instrument calibration and prints the absolute spectral irradiance of the UV source being measured. The calculator also controls the operation of the spectroradiometer so that, on command, scanning is begun and readings are recorded for each nanometer interval. The calculator prints the wavelength and spectral irradiance for each wavelength interval, sums the absolute and biologically effective UV radiation (based on a programmed action spectra) for desired band widths and, at the end of each

scan, reverses the wavelength drive and returns the monochromator to the starting wavelength. At the completion of the scan, the data can be stored on a magnetic tape for future analyses or transferred to an automatic plotter. A miniature low-pressure mercury-arc lamp is used to provide a precise check of wavelength accuracy. The calculator computes the position of the 253.7-nm and the 296.7-nm mercury lines to a precision of $\pm$ 0.01 nm.

In order to provide investigators in the program with a simple instrument for monitoring the output of artificial UV sources in laboratory, greenhouse, and growth chamber studies, broad-band and narrow-band UV radiometers were also developed by the Instrumentation Research Laboratory. These instruments feature a teflon bubble cosine receptor, a solar-blind phototube, a battery-powered photometer circuit and a small rugged housing. In order to provide a basis for interlaboratory comparisons of UV data, the sensitivity of the broad-band radiometer was adjusted to give the same full scale reading under a common UV source (FS40 fluorescent sunlamps filtered with 5 mil cellulose acetate). Correction factors were developed for use under other lamp-filter combinations.

The specifications for these instruments were made available to industry, and commercial models have now been developed and obtained by cooperating locations.

Spectral Characteristics of Fluorescent Lamps and Testing of Weighting Functions

The Agricultural Equipment Laboratory at Beltsville, Maryland, developed mathematical equations describing the distribution of normalized UV irradiance levels in any desired combination of lamps, either parallel or end-to-end, at any defined distance of the lamps from the illuminated surface. A computer

program was written which permitted scientists to accurately design biological experiments and interpret the results.

Lamp fixtures were fitted with specially designed reflectors to provide greater uniformity and reproducibility in UV radiation experiments. Multiple fixture assemblies were designed and built.

An average or standard spectral distribution of UV energy of the sun for the Middle Atlantic area was derived from data collected by the Smithsonian Radiation Laboratory, Rockville, Maryland, in June-July 1976, and by the Instrumentation Laboratory, Beltsville, Maryland. This is now being used by Beltsville scientists as a base for design of UV enhancement experiments.

In conjunction with the Florist and Nursery Crops Laboratory and the Plant Stress Laboratory, experiments with higher plants were undertaken to more clearly define the weighting function that must be used to interpret results, since the spectral distribution of the fluorescent lamps does not duplicate that of the sun. Several weighting functions were investigated. The equation providing the best fit was derived and is being used by the majority of investigators. We are continuing to obtain data testing the applicability of this weighting function.

Biological Effects of UV-B Radiation on Plant Growth and Function

Greenhouse, growth chamber, laboratory, and field studies were conducted by the Plant Stress Laboratory at Beltsville, Maryland, on a wide range of vegetable and agronomic crops to determine the relative sensitivity or resistance to increased UV-B radiation. Data were collected on various physiological responses to increased UV-B radiation including: photosynthesis, respiration, ion uptake, translocation of radioisotopes, stomatal activity, changes in chlorophyll and anthocyanin content, leaf movement, germination,

seedling growth and reproductive development. Studies were also conducted on UV-B interactions with plant disease organisms.

Broad-band UV-B studies were conducted in the greenhouse and growth chamber on over 20 species and cultivars of vegetable and agronomic crops. Plants were exposed to a gradient of UV-B radiation representing a 50 to 500 percent increase in biologically effective UV radiation. Plants studied included cotton, peanut, wheat, rice, alfalfa, cucumber, pea, beet, tomato, rutabaga, okra, bean, radish, and turnip. Most plants were exposed to UV-B for 4-5 weeks from time of planting the seed, but a few (wheat, rice, alfalfa, cotton) were grown to maturity under elevated UV-B. Visual injury was observed in over half of the species and cultivars studied. In most cases only slight or moderate UV damage was noted even when the plants were exposed to an increased level of biologically effective UV radiation as high as 300-400 percent.

The most dramatic evidence of UV-B injury was chlorosis in pea and cucumber, necrosis in pea leaves and pods, and reduction in leaf size in pea and cucumber.

Dose-response studies conducted on cucumber varieties demonstrated significant differences in UV-B sensitivity; Poinsett cucumber was extremely sensitive and Ashly cucumber was only slightly sensitive. Evidence was obtained for UV-B induction of chlorosis of the leaves, inhibition of leaf enlargement, and reduction in biomass. These effects were most pronounced under conditions for low photosynthetically active radiation, and high UV-B exposure.

High levels of UV-B irradiation in the greenhouse (100-400 percent increase in biologically effective UV) reduced the total number of kernels in Pacific Triple Dwarf wheat by 20 percent, but had no appreciable effect on the average yield.

Translocation of radioactive zinc from the cotyledons to other plant parts of the young cotton was not influenced by a 100-400 percent increase in biologically effective UV; however, the transport of radioactive calcium was depressed 12-30 percent over this range of UV irradiation.

Based on linear regression analysis of plant data obtained in the greenhouse of one of the more sensitive plants (Poinsett cucumber) exposed to increased UV irradiation (from 50-300+ percent increase in biologically effective UV), it was estimated that a maximum decrease in stratospheric ozone content of 20 percent would cause a 10 percent reduction in dry matter accumulation and a 15 percent decrease in leaf area. It is not possible at the present time to determine whether these estimates can be applied to other species of higher plants.

Measurements were made on net photosynthesis rates, plant biomass production, stomatal diffusive resistance, and transpiration rates in selected plants of snap bean, clover, cotton, cucumber, and wheat irradiated in the greenhouse and growth chamber. In general UV-B effects on net CO_2 exchange rates and foliar gas exchange were correlated with the amount of visible injury induced.

Chromatography and subsequent UV and visible spectroscopy of acidic methanol extracts of Coleus blumei leaves taken from UV-B irradiated plants demonstrated a degradation in UV absorbing compounds. Similar results were obtained with reflectance measurements. Increasing the UV-B irradiance resulted in increased degradation of anthocyanin pigment, reduction in the rate of leaf expansion, inhibition of apical growth, and abnormal development of the leaves.

Field studies were conducted on UV effects at Beltsville on a range of agronomic and vegetable crops using a gradient of UV radiation developed by the Agricultural Equipment Laboratory. Crop plants studied included Contender bush bean, Early Prolific straightneck yellow squash, Amsoy-71 soybean, sugar beet, Golden Cross Bantam corn, R-720 sorghum, and Waltham 29 broccoli. A fall crop of winter grains was also grown that included Potomac, Redcoat, and Abe wheat, Pennard and Monroe barley, and Abruzzi rye.

Increasing the biologically effective UV radiation by 100 percent had no visible or consistent effect on crop performance under field conditions.

Plant Disease Interaction with UV-B Radiation

The Plant Stress Laboratory has studied the effects of UV-B radiation on plant diseases. The results of increased levels of UV-B irradiance on spore germination indicate that although plant leaf pathogenic fungal species vary considerably in sensitivity to UV-B, relatively high irradiance levels are required to reduce germination percentage. Pigmented spores such as *Cladosporium*, *Stemphyllium*, and *Alternaria* were found to be more resistant to increased UV-B irradiance than hyaline spores (*Mycosphaerella*, *Colletotrichum*).

Disease severity of *Colletotrichum lagenarium* on cucumber was decreased with increasing UV-B irradiances. A linear decrease in the percentage of leaf area diseased with increased irradiances was found.

Increased levels of UV-B irradiance did not affect disease severity of *Cladosporium cucumerinum*. The disease tended to reduce plant growth equally regardless of UV-B irradiance levels.

There was no noticeable UV-B effects on either the *Stemphyllium botryosum* pathogen or the host, alfalfa.

In summary, recognizing that our results represent only a small sampling of leaf disease organisms and of plant disease-interaction experiments, they appear to support the following: (1) considerably higher levels of UV-B irradiances than those expected from the projected ozone depletion will be required to adversely affect germination and growth of pathogenic fungi, and (2) where fungal germination and growth are affected, disease severity in the host plant can be expected to be reduced as UV-B irradiances increase.

Response of Florist and Nursery Crops to Increased UV-B Radiation

Greenhouse and growth chamber studies were conducted by the Florist and Nursery Crops Laboratory at Beltsville, Maryland, on a wide range of florist and nursery crops to determine their relative sensitivity or resistance to increased UV-B radiation. Selected plants were also chosen for reflectance and fluorescence measurements and for microscopic examination in the laboratory. After 2-8 weeks of exposure, visible injury was observed in eight of the 58 species irradiated, and then only when applied in excess of projected levels of UV-B radiation expected to result from CFM-catalyzed reduction of stratospheric ozone.

The most typical response to high levels of UV-B irradiation (100 percent or greater increase in biologically effective UV) included breakdown of chlorophyll and anthocyanin and a glazing and browning of the tissue, generally attributed to the presence of oxidized, polymerized, phenolic compounds. Other effects observed in some of the test plants included abnormal leaf growth, characterized by reduced size, twisting and distortion, and reduced plant height. Plant biomass was generally unaffected when mature plants were irradiated; biomass of young seedlings, however, was frequently depressed under high UV-B.

There was considerable variation in sensitivity to UV-B exposure, depending upon species and cultivar, stage of development, time of year, and level of exposure. In general, herbaceous plants were more sensitive to increased UV-B than were woody plants. *Fatsia japonica* was the only woody species of the ten tested that showed inhibitory effects of high UV-B.

Plants irradiated during the summer months in the greenhouse showed little or no UV injury, even under the highest levels of UV-B used. This was in sharp contrast to the spring and winter months when they showed considerable injury under the same level of UV irradiance.

Poinsettia, *Coleus*, and *Browallia* were among the most sensitive examined. Other species sensitive to increased UV-B irradiation included aster, hollyhock, vinca, and impatiens.

In order to develop a capability for understanding the basic cellular and ultrastructural mechanisms of UV-B effects, a UV microspectrophotometer was obtained and assembled in the Florist and Nursery Crops Laboratory. This instrument will enable researchers to irradiate single cells or cellular constituents as small as 0.5 micrometer with narrow band UV radiation, to make rapid scans of absorbance and reflectance in the region of 250-1000 nm, and to make precise measurements of UV fluorescing materials. A programmable calculator was also obtained to control the instrument and to provide on-line data acquisition, processing, storage, and display.

Influence of Solar UV-B Radiation on Crop Productivity

Greenhouse, growth chamber, and field studies were conducted by the Fruit Crops Department, University of Florida, Gainesville, Florida, on a wide range of vegetable and agronomic crops to determine their relative sensitivity or resistance to increased UV-B radiation.

Field studies were conducted at Gainesville under specially constructed UV-B gradients obtained by mounting the fixtures at an angle over raised plant beds. Crops grown to marketable size and maturity included corn, potatoes, tomatoes, field peas, peanuts, rice, squash, mustard, and radish. Visual effects were observed in corn and rice under high UV-B irradiances (100 percent or greater increase in biologically effective UV). Both crops appeared dwarfed and the grain head of the rice plants were slower to mature than the unirradiated controls.

Growth chamber studies were conducted by University of Florida researchers at the Phytotron at Duke University in Durham, North Carolina. Over 100 species and varieties of agronomic, horticultural and forest plants were grown from seed for 4-12 weeks under increased UV-B radiation. Under high levels of biologically effective UV-B radiation (100 percent or greater increase) plants exhibited a number of abnormal responses. These included: Marginal and interveinal chlorosis; cupping and epinasty of the leaves; changes in pigmentation; increased branching; reduced vineness; and reduction in height, leaf area, and biomass.

In general, plants within the same family responded similarly to increased UV-B radiation. By using controlled environment studies it was possible to identify varieties of soybeans that are sensitive to present levels of UV-B radiation at Gainesville, Florida.

Preliminary studies conducted in the Phytotron with Jori wheat and Hardee soybean, at four levels of UV-B radiation and four levels of visible radiation showed that the extent of UV-B radiation damage was greatly influenced by the amount of visible radiation present. Other research accomplishments of the Univeristy of Florida scientists included developing

an action spectrum for pigment induction in the avocado leaf having a maximum effectiveness in the UV-B region at 295 nm. These investigators also found that increasing the level of biologically effective UV radiation by up to 100 percent had no significant effect on structural changes or chemical composition of surface waxes of tomato and pepper plants. Agronomic plants subjected to high levels of UV-B radiation also produced increased amounts of ethylene and accumulated larger quantities of abscisic acid than control plants.

Response of Vegetable Crops to High UV-B Radiation at High Elevations

UV-B enhancement and exclusion studies were conducted by the Department of Horticulture, Colorado State University, at a 3000 m site elevation in the Rocky Mountains.

Supplementing natural solar radiation with additional UV-B radiation had no significant effect on the growth and biomass of pea, radish, potato, and wheat grown at this elevation. Shielding wheat plants from natural solar UV-B, however, resulted in an increase in size of the plants.

Other accomplishments included the development of transmission spectra for a chlorinated-fluorinated resin film "Aclar" found to be useful in aquatic studies as a UV transparent film; development of an assay for detecting loss of electrolytes from UV-irradiated plant tissues; characterization of the influence of low temperatures on decline in lamp output of UV fluorescent sun lamps; and design of a solar UV-B collector and irradiator.

Response of Arid and Semi-arid Plants to Increased UV-B Radiation

SEA scientists at Las Cruces, New Mexico, investigated selected native and economically important species indigenous to the arid southwest United States. Plants were exposed to increased UV-B irradiation in the greenhouse.

Dose response studies were conducted on alkali sacaton (*Sporobolus airoides* Torr.), mesa dropseed (*S. flexuosus*) and Chile pepper (*Capsicum frutescens*). Alkali sacaton and Chile pepper plants exposed to high UV-B showed a marked reduction in leaf growth with increasing UV-B. Mesa dropseed plants, however, showed no differences in leaf growth between UV-B-irradiated and control plants. Dock plants (*Rumex patientia* L.) exposed to high levels of UV-B showed a reduction in protein synthesis.

Impact of Solar Radiation on Crops and Crop Canopies

Physiological and ultrastructural studies were conducted by SEA researchers at Gainesville, Florida, on selected vegetable, agronomic, and citrus crops exposed to increased UV-B radiation in the field and the greenhouse.

Citrus plants irradiated for 4 weeks under supplemental UV-B radiation in the field showed no significant reduction in average daily photosynthetic rate as compared with unirradiated control plants even under a 200 percent increase in biologically effective radiation. Similar results were obtained in stomatal diffusion resistance of eight soybean varieties.

Broad-band UV-B enhancement studies were conducted in the greenhouse on soybeans (Bragg and Altona), peas (Little Marvel), tomatoes (Rutgers) and sweet corn (Golden Cross Bantam). Plants were grown for 4-6 weeks under three levels of UV-B irradiation ranging from approximately a 100-200 percent increase in biologically effective UV. Data were taken on biomass, CO_2 uptake rate, chlorophyll content, Hill reaction, RuDP carboxylase, PEP carboxylase, soluble proteins, absorption spectra of pigment extracts, and ultrastructural changes in selected cultivars.

In general, plants exposed to high UV-B irradiation in the greenhouse showed physiological changes. For example, soybean plants showed a decrease in chlorophyll content, RuDP carboxylase activity, soluble protein content, CO_2 uptake, and fresh and dry weight as compared with control plants receiving only UV-A (320-400 nm) irradiation alone or unirradiated control plants. In contrast, plants given supplemental UV-B irradiation in the field showed little or no effect.

Differences in species and cultivar response to increased UV-B irradiation were also observed. Differences in chemical and structural makeup of the epidermis and palisade parenchyma cells were thought to play a role in the response of different plants to enhanced UV-B radiation.

Response of Woody Plants to Increased UV-B Radiation

Various physiological disorders of agronomic and horticultural crops and woody species have been ascribed to high levels of solar irradiation, especially at high elevations. In order to determine the role of UV-B radiation in solar injury of certain woody plants at high elevations, Forest Service scientists conducted UV-B enhancement and exclusion studies at the Rocky Mountain Forest and Range Experiment Station in Fort Collins, Colorado. Englemann spruce was chosen as a sensitive species and Lodgepole pine was chosen as resistant species.

Seedlings were irradiated under artificial UV lamps for a total of 400 hours over a 67-day period or were grown under various filters to exclude natural UV-B radiation. No evidence of UV injury was observed in any of the treatments during the first year of the study. Since Engelmann spruce seedlings transplanted to the natural environment do not show symptoms of solar radiation injury until after the first winter, seedlings will be observed for symptoms during the second growing season.

Response of Nitrogen-fixing Organisms to Increased UV-B Radiation

Nitrogen fixation of Anabena floss-aquae and other blue-green algae, free-living and in symbiosis with the water fern Azolla, is important in rice culture and in worldwide soil fertility. Laboratory studies were, therefore, conducted at the SEA Northern Regional Research Center in Peoria, Illinois, on the influence of increased UV-B radiation on the nitrogen fixing abilities of Anabena alone and in association with Azolla.

Results indicated that while viability and photosynthesis of Anabena cells were unaffected by UV-B irradiation, nitrogen fixation (as measured by nitrogenase activity) was markedly reduced by high levels of UV-B irradiation.

When cultures of blue-green algae were exposed to 10 watts/m^2 of UV-B for 3-5 hours, the algal nitrogenase was inhibited to about one-half of the activity of the control cultures. In spite of this observed reduction in nitrogenase activity there was no reduction in the treated cells' reproductive capacity as demonstrated by plate count studies.

When blue-green algae and its symbiont Azolla were exposed for 4-6 days with 10 watts/m^2 of UV-B, photosynthesis ($C^{14}O_2$ fixation) was not affected, and nitrogenase activity was reduced to 30-40 percent of that observed in the control.

Response of Farm Animals to Increased UV-B Radiation

Studies conducted by SEA researchers at the National Animal Disease Center in Ames, Iowa, investigated the carcinogenic effect of high levels of UV-B irradiation on the eyes of four Hereford cattle. Exposing eyes of these cattle to high levels of UV-B irradiation for 2 hours per day induced ocular changes that were consistent with chronic irritation. After 7 months of exposure, one animal developed ocular changes that were considered neoplastic after biopsy and pathological examination. Cancer eye, a squamous

cell carcinoma, normally takes 5-6 years to develop in cattle under natural conditions.

Inspection of slaughterhouse condemnation records was made to determine the extent and incidence of cancer eye in cattle, using USDA Meat and Poultry Inspection data. Based on the total cattle slaughtered since 1950, the increase in cancer eye was about two-fold. Since other diseases of cattle have also increased during this time period, it is difficult to interpret these data.

Response of Insects to Increased UV-B Radiation

Studies were conducted in the Chemical and Biophysical Control Laboratory at Beltsville, Maryland, on the influence of increased UV-B radiation on the physiology and behavior of selected beneficial and harmful insects. These studies demonstrated that lightly pigmented insects, such as the pink bollworm, codling moth, and the face fly, were much more sensitive to exposure to UV-B irradiation than heavily pigmented ones such as the house fly.

Brief exposure of pink bollworm eggs to UV-B radiation levels (10-50 percent above natural levels at Beltsville), for 1 to 3 hours greatly reduced the life span of larvae hatching from these eggs. High UV-B levels (100 percent increase in biologically effective radiation) also had a highly lethal effect on face fly pupae irradiated for 1 hour per day for 3 days.

Adult honeybee workers, however, were able to tolerate a 10-50 percent increase in UV-B radiation for 6 hours per day for 6 days without apparent injury.

High UV-B irradiation increased pigment formation in the larvae of butterflies and moths, and the pupae of face flies, but had little or no effect on the pigment content of tobacco budworm larvae, house fly pupae, or honeybees.

Physiological studies on respiration indicated an increase in oxygen uptake in codling moth larvae irradiated 6 hours per day for 2 days, but no effect on honeybee workers.

Tobacco budworms allowed to feed on bean leaves exposed to UV-B irradiation did not show increased mortality. The eggs of pink bollworms, however, irradiated on cotton leaves showed a reduction in number that hatched.

Stability of Agricultural Chemicals Under Increased UV-B Irradiation

The Organic Chemical Synthesis Laboratory at Beltsville, Maryland, constructed and successfully put into operation a "merry-go-round" type photolysis apparatus for investigating the stability of pesticides and other agricultural chemicals under increased UV-B irradiation. Such studies are being conducted to determine the efficacy of various agricultural chemicals under a high UV-B environment.

Photodegradation of test compounds was obtained by exposing the samples to 313 nm radiation in the UV-B region and quantum yields measured. Preliminary studies with aqueous solutions of pesticides confirmed the dependence of quantum yield (the number of pesticide molecules consumed per quantum of UV-B radiation absorbed) upon concentration.